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Experimental scoliosis in monkeys

Scoliosis was produced experimentally in monkeys, by excision of ribs and costo-transverse ligaments. Unilateral excision of these structures produced mild reversible scoliosis, while bilateral excision caused a severe structural curve. We feel that scoliosis so produced is due to instability of the spine which is more pronounced in bilateral operations.

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Many attempts have been made to establish a suitable experimental model of scoliosis (Robin 1966, Nordwall 1973), the most consistent production of scoliosis having been reported by Langenskiöld & Michelsson (1962) in rabbits. We attempted to produce scoliosis in monkeys; because of their semi-upright posture and nearness on the phylogenetic scale, such a model would permit comparison with human idiopathic scoliosis.

Material and methods

The study was conducted on 30 monkeys, which were divided into three groups of 10 each:

Group 1: Resection of the dorsal end of the lower six ribs on the right side.
Group 2: Removal of the costo-transverse ligament of the lower six costo-vertebral joints on the right side.
Group 3: Resection of the dorsal end of the six lower ribs on the right side, followed 6 weeks later by resection of the corresponding ribs on the left side.

Young monkeys (less than 2 kg) with a sufficient growth potential were selected. They were anaesthetised with i.v. thiopentone sodium (50 mg/kg). The monkey was then strapped to the operating table, cleaned and draped. A paravertebral incision was made 1 cm from the midline. The trapezius was freed from the spinous processes and the erector spinae was retracted medially. The laminae, transverse processes and ribs were cleared subperiosteally.

The dorsal ends of the ribs were resected up to 1 cm from the transverse process. The costo-transverse ligaments of the lower six ribs and the corresponding intercostal muscles were divided.

Operative complications like pneumothorax were occasionally seen, but were not serious. Mortality during or immediately following operation was low. Post-operatively, the animals were left free within the cage on a normal diet. Streptomycin and penicillin were given intramuscularly for 5 days.

The animals were studied clinically and radiographically, and then sacrificed for a macroscopic study of the vertebral column.

Clinical examination. The animals were examined clinically to study:

1) The presence of scoliosis and the site and side of convexity;
2) The severity of deformity and rotation, if any;
3) Whether the curve could be corrected by lateral and forward flexion of the spine;
4) Any change in posture and gait of the monkey.

Radiographic examinations. Antero-posterior radiographs of the spine were taken before surgery and 48 h and 6 weeks postoperatively; Cobb's method was used to measure the curves.

Macroscopic examination. The monkeys were sacrificed 6 weeks after surgery, and the vertebral column was dissected out from the first cervical to the last lumbar vertebrae along with the thoracic cage. The structural changes in the spine were then studied. The fixed specimens were photographed and radiographed.

Results

There was no evidence of scoliosis on inspection and palpation either in the immediate post-operative period or 6 weeks after surgery in Groups 1 and 2. The ability to assume an erect posture or climb bars in the cage was not disturbed. In Group 3, a fairly significant structural scoliotic curve could be demonstrated 6 weeks after the second operation in seven out of 10 monkeys. The curve was rigid and did not

Table 1. Radiographic examination of the curve after resection of the dorsal end of the lower six ribs (Group 1, No. 1–10) and after removal of the costotransverse ligament of the lower six costo-vertebral joints (Group 2, No. 11–20)

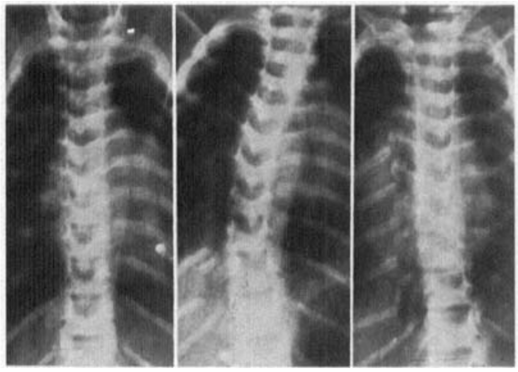
No.	48 h postoperatively		After 6 weeks	
	Cobb's angle	Rotation	Cobb's angle	Rotation
1	18	+	0	+
2	20	+	0	+
3	0	–	0	+
4	0	–	0	–
5	23	+	0	+
6	0	+	7	+
7	12	–	0	–
8	0	–	5	+
9	0	–	0	+
10	7	–	0	+
11	0	–	10	–
12	0	–	5	–
13	15	–	0	–
14	5	–	5	+
15	0	–	5	+
16	0	+	12	+
17	0	–	0	–
18	15	+	0	–
19	0	–	0	–
20	0	–	0	–

disappear on lifting the animals. Lateral flexibility of the spine was reduced. The primary curve was in the dorsal region with its convexity to the left. Rotation of the spine was quite evident.

Table 2. Radiographic examination of the curve after resection of the dorsal end of the six lower ribs on the right side, followed 6 weeks later by resection of the corresponding ribs on the left side (Group 3, No. 21–30).

No.	Right				Left			
	1		2		1		2	
	A	B	A	B	A	B	A	B
21	25	+	5	+	10	+	40	+
22	21	+	0	–	32	+	50	+
23	20	+	0	–	10	+	5	+
24	23	+	20	+	10	+	40	+
25	28	+	0	–	–	–	–	–
26	12	+	0	–	–	–	–	–
27	5	+	0	+	0	+	33	+
28	22	+	0	+	–	–	50	+
29	0	+	0	–	60	+	65	+
30	10	+	0	–	–	–	–	–

1 = First postoperative radiograph after 2 days.
2 = Second postoperative radiograph after 6 weeks.
A = Cobb's angle.
B = Rotation.



A B C

Figure 1. Group 1. Excision of ribs alone.
A. Pre-operative;
B. 2 days after surgery, right sided scoliosis (Cobbs angle 23°);
C. 6 weeks after surgery, disappearance of the curve.

Radiographic examination

In both Groups 1 and 2, only a few monkeys showed the presence of a mild scoliotic curve 48 h after surgery, and this had disappeared in most animals 6 weeks after surgery (Table 1, Figure 1). Rotation was seen only in three animals in Group 1 and in one in Group 2. In Group 3, all animals had a minimal scoliosis 48 h after the excision of the ribs, with an average angle of 16 degrees (Table 2). Six weeks later, the curve had disappeared completely in eight out of ten animals but rotation persisted in four. Radiographs taken 48 h after the second operation showed well-marked scoliosis in two animals and mild scoliosis in one. All radiographs 6 weeks after the second operation showed a significant progressive scoliosis; in the seven surviving animals the degree of the curve was on average 46 (33–65) degrees. Rotation of the bodies and crowding of ribs on the concave side were seen in all the radiographs (Figure 2). Specimen radiographs (Figure 3) also showed a well-marked rotation.

Macroscopic examination

In Group 1, a mild degree of scoliosis was seen in two specimens. In Group 2, only three out of ten specimens showed a mild scoliotic curve (Figure 3). Interestingly, four animals with mild curves (10 degrees) after 48 h did not show any scoliosis macroscopically. In Group 3, on the other hand, a definite, rigid, scoliotic

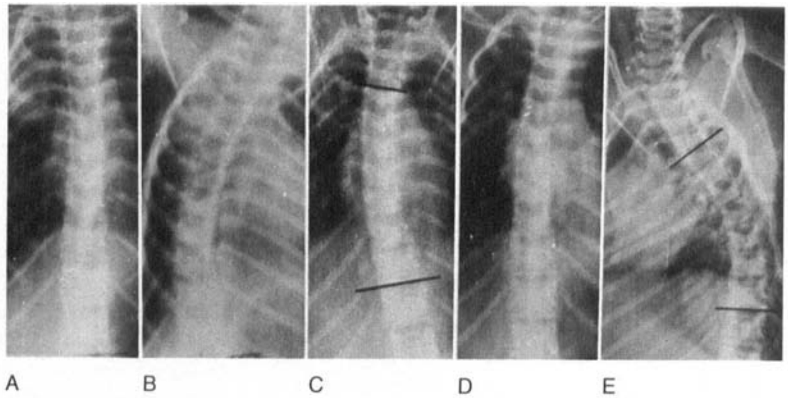


Figure 2. Group 3. Excision of ribs on right side followed 6 weeks later by excision on left side.
A. Preoperative;
B. 2 days after surgery on right side, a mild scoliosis (23°) with rotation;
C. 6 weeks after surgery, a mild scoliosis (20°);
D. 2 days after excision of ribs on left side, a mild scoliosis (10°);
E. 6 weeks after surgery, a scoliosis of 40° with rotation.

curve was seen in seven specimens with significant rotation of the vertebral bodies (Figure 3). The thoracic wall was definitely asymmetric, the concave side being markedly narrower than the convex side. A hump was seen. The ribs on the convexity were rather vertical.

Discussion

Experiments in quadrupeds to produce scoliosis have been carried out by many workers (Langenskiöld & Michelsson 1961, Bobechko 1973, Nachlas & Borden 1950, Kent & Zingg 1974). The static and dynamic conditions of the spine are different in man and quadrupeds. Hence a primate was chosen as an experimental model since the monkey is the animal nearest to man on a phylogenetic scale and often maintains a sitting and sometimes a semi-erect bipedal posture; hence it is an ideal subject for scoliosis. Stilwell (1962) first attempted to produce scoliosis in monkeys, but on a careful review of his article production of scoliosis is not evident; it is also not clear how many animals developed kyphoses rather than scoliosis. Later, Robin & Stein (1975) were unsuccessful in producing scoliosis in baboons.

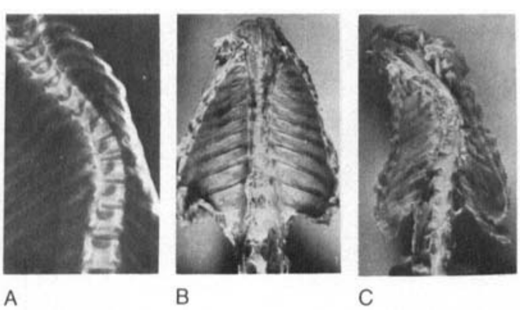


Figure 3. Post-mortem specimens. A. Group 3. Marked scoliosis with rotation and deformity of thoracic cage.

B. Group 2. Post-mortem specimen, no scoliosis or rotation.

C. Group 3. Post-mortem specimen. Marked scoliosis with deformity of the thoracic cage. Note the crowding of ribs on the concave side.

Surgery on the structures around and attached to the vertebral column has invariably failed to produce significant scoliosis consistently. Excision of muscles (Schwartzmann & Miles 1945, Stilwell 1962), denervation by transection of the phrenic nerve (Miles 1947), and stapling of growth plates have resulted in only mild scoliosis occasionally.

We feel that in our experiments the active forces were weakened on the side of operation, thus leading to scoliosis; as the corresponding forces on the opposite side remained effective, progression of the scoliosis was not seen. This was also observed by Michelsson (1965) in his experiments. He found intense regeneration of affected tissues, particularly in the youngest animals, and this sometimes resulted in almost complete restoration of the anatomical conditions; sometimes scar tissue completely compensated for weakened or removed structures, and occasionally it even caused transition of the scoliosis to the other side (Michelsson 1965).

Although excision of the costo-transverse ligament is known to produce scoliosis (Langenskiöld & Michelsson 1962), we did not see a significant curve even after 6 weeks, an observation also made by Robin & Stein (1975). Excision of the ribs on the side opposite to the curve has been known to regress the curve both experimentally (Michelsson 1965) and in clinical practice (Piggot 1971).

The production of scoliosis in our experiments depended on whether the operation was performed on one or both sides of the spine and not on the type of surgery or the animal. According to Michelsson (1965), the dorsal end of the rib constitutes a lever. Operations involving the rib articulation affect its attachment to the spine, thus reducing the forces acting via the ribs, and resulting in scoliosis on the side of the operation.

We believe that the development of scoliosis was due to the altered balance of forces caused by the surgical procedure. The normal fixation of the vertebrae to each other and to the ribs prevents rotations and lateral movements at the dorsal spine. Normally the static and stronger dynamic forces (Carey 1932, Steindler 1955) keep the spine in a state of dynamic equilibrium (Steindler 1955). Operation on the dorsal ends of ribs upsets this balance and causes rotation. When one side is operated on, the normal side prevents the deformity from occurring; operation on the second side takes away the entire support to the spine, resulting in scoliosis. A strong confirmation of this belief was provided by the much more severe curve occurring after the second operation.

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